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Salinity: A Nonpoint Source Problem

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MANAGING HEADWATER AREAS FOR CONTROL OF SEDIMENT AND SALT PRODUCTION FROM WESTERN RANGELANDS

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ABSTRACT

Control of nonpoint source water pollutants poses special challenges on western rangelands. The public rangelands managed by the Bureau of Land Management are often characterized by unstable sedimentary geologic parent material, semiarid climate, and sparse vegetation. Intense summer thunderstorms produce locally heavy runoff. Where marine shales are exposed at the surface, their sediments often contain high concentrations of soluble salts. The immense size of the sediment- and salt-producing areas poses treatment problems, both from a technical and economic standpoint. Treatment objectives include retention of runoff water and stabilization of actively eroding gullies in headwater areas. Watershed improvement projects are designed to provide multiple resource benefits, such as water supplies for livestock and wildlife, improvement of water quality, and retention or enhancement of site primary productivity. Two representative watershed improvement projects are described: Sheep Creek Resource Conservation Area in southern Utah and Lower Missouri Creek Tributaries Stabilization Project in northwestern Colorado.

Sediment and salts are major nonpoint source, water quality constituents on western rangelands. They occur naturally in runoff but may be increased by management activities and become issues when they affect beneficial uses of water. Sediment production is highest on lands with steep slopes, sparse vegetation cover, and erodible soils—common conditions on western U.S. rangelands (U.S. Dep. Agric., 1980). Salinity is a problem in the Colorado River Basin where eroded sediments have naturally high soluble salt contents (Hawkins et al. 1977; U.S. Dep. Inter. 1978). Public lands in the upper Colorado River Basin produce about 650,000 metric tons of salt annually, or about 8 percent of the upper basin salt load from diffuse overland sources (U.S. Dep. Inter., 1978).

We recently reported on the approach the Bureau of Land Management (BLM) uses to identify nonpoint sources of pollution on public lands (Van Haveren et al., 1985). In this paper we describe the specific strategies and control technologies BLM has employed to reduce salt and sediment production on western rangelands.

CONTROL PLANS

Developing effective salt and sediment control plans requires: (1) the establishment of resource management objectives, (2) the identification and quantification of manageable hydrologic processes, (3) the investigation of cause and effect relationships, (4) the stratification of treatment areas, and (5) the selection and evaluation of alternative treatment techniques.

Whichever watershed management techniques are eventually implemented, multiple resource values may be affected, including forage production, water supplies for livestock and wildlife, improved water quality, enhanced wildlife habitat, reduced soil loss, control of downstream flooding and channel erosion, and reductions in downstream sediment and salt delivery. The overall goal in developing sediment and salinity control plans is to provide an optimum mixture of resource benefits consistent with overall resource management objectives.

Establishment of Objectives

Objectives for controlling salt and sediment should relate to both the processes to be influenced and the management goals to be achieved. In establishing management objectives for sediment and salinity control, corresponding objectives need to be established for related, affected resource values. This will enable a meaningful analysis of tradeoffs associated with alternative treatment techniques. If possible, objectives need to be quantified so that progress in achieving them can be effectively monitored and evaluated.

Identification and Quantification of Manageable Processes

The identification and quantification of manageable processes and variables is accomplished as part of the watershed analysis procedure (Solomon et al. 1982; Gebhardt, 1985). However, more detailed or site-specific quantification may be required for project design or for ranking individual treatment alternatives. Most sediment and salinity control projects require information on both long-term and runoff and sedimentation rates, and single-storm design values for runoff, peak flows, and sediment yield.

In quantifying manageable salt and sediment processes, it is useful to distinguish between natural and management induced problems. Generally BLM prefers to correct management induced problems rather than control natural processes.

Investigation of Cause-and-Effect Relationships

Distinguishing between causes and effects is very important when evaluating sediment and salinity problems. For example, high gully erosion rates may be the result of local or regional changes in base-level controls, or they may be caused by runoff in excess of the thresholds, the reduction of streamside vegetation, or some combination of causes. Proper identification and quantification of the causes of a problem will more likely lead to the proper selection of treatment techniques than will a simple quantification of the problem symptom (such as erosion rates). Of particular importance in investigating salinity issues is the relationship between sediment and salt. Where highly saline soils are eroding, we assume that controlling sediment will also control salt. However, other salt transport mechanisms, including interflow and ground water flow, may not be manageable by controlling runoff and erosion.

Stratification of Treatment Areas

Where large watersheds (>50 km^2) are to be treated, we recommend dividing the area into treatment units. The stratification is based on topographic considerations, including soils and vegetation, salt and sediment source areas, locations where controlling processes can be managed, and treatment potential. After identification, treatment units are ranked, based on both the sediment or salt production rating and treatability of the area. The application of this concept to the Lower Wolf Creek watershed is discussed later in this paper.

TREATMENT TECHNIQUES

Controlling salinity in surface runoff from rangelands is closely related to controlling soil erosion. Vegetation cover is usually the most important management variable influencing runoff and erosion rates on rangelands.

Therefore, vegetation management, either directly through vegetation manipulation or indirectly through the design and implementation of livestock grazing plans, is an important erosion and salinity control technique. However, on the most highly saline rangelands, maximum potential cover is usually too low to provide meaningful control of surface runoff and erosion. In these cases, or in situations where the watershed's condition is so severely degraded by past management practices that natural recovery will be inefficient, mechanical land treatments and structural alternatives may be the most effective erosion and salinity control techniques.

Vegetation Management

Vegetation cover, including canopy cover, ground cover, and litter, reduces upland soil loss by protecting soil from direct raindrop impact and by reducing surface runoff velocities. Vegetation also intercepts rainfall and enhances soil infiltration properties, thus reducing runoff volume and its erosive capacity, both on hillslopes and in stream channels.

Livestock grazing affects vegetation cover by influencing species composition, vigor, production, and forage use. Most studies have shown that runoff and erosion increase with grazing intensity (Lusby, 1979a; Gifford and Hawkins, 1978). Generalized relationships between livestock grazing and vegetation cover, however, have not been forthcoming. Common erosion estimation techniques, such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978), that require information on vegetation cover are difficult to apply given information only on livestock grazing or forage use. Thus, it is difficult to accurately predict the effects of livestock grazing systems on erosion. Nevertheless, proper land use, including well-designed grazing systems, is the preferred method of achieving watershed management objectives (Moore et al. 1979; Van Haveren et al. 1985).

The most common techniques for direct vegetation manipulation on rangelands include pinyon-juniper control and big sagebrush control. Both techniques involve eliminating pinyon-juniper or big sagebrush stands by mechanical or chemical means or burning. Either native grasses and forbs are permitted to reestablish naturally or grasses are planted. General conclusions concerning the effectiveness of vegetation conversions in reducing runoff and soil loss on rangelands are not available. However, the many discrepancies in the literature suggest that vegetation manipulations may not be reliable techniques for controlling sediment and salinity. In many cases, vegetation conversions have resulted in more desirable forage species for livestock, but have not significantly reduced runoff or soil loss (Williams et al. 1972; Gifford et al. 1970; Gifford, 1972; Gifford and Busby, 1974; Blackburn and Skau, 1974). In some cases involving sagebrush conversion to grass (Lusby, 1979b) runoff and sediment yield have been reduced significantly.

Mechanical Land Treatments

Mechanical land treatments involve soil tillage techniques such as contour furrowing, ripping and pitting. Tillage is generally applied to increase infiltration volumes. This may be accomplished by increasing infiltration capacities or depression storage (thus, the time available for infiltration), or both. When successful, runoff and erosion can be reduced. Salinity benefits will be proportional to the amount of salt in the controlled runoff and sediment. If improved soil moisture regimes improve vegetation cover, benefits derived from mechanical land treatments may be sustained indefinitely, given compatible subsequent land use management. If improved cover is not achieved or maintained, benefits from mechanical land treatments may be short-lived.

Contour furrows are usually constructed within a reseeding and grazing management program, primarily to increase depression storage and the time available for infiltration. Furrows are not recommended on slopes greater than 10 percent, and are most effective in medium to fine textured soils. Furrows have finite lives (Branson et al. 1966) that are a function of their storage capacity in relation to runoff and erosion at the site. When functioning properly, they eliminate most runoff from a site.

Ripping, unlike furrowing, generally influences depression storage very slightly; the main benefits must be achieved by increasing soil infiltration capacities. This is most effective on severely compacted soils such as on roads or reclaimed mined lands, or on soils where a shallow pan layer restricts downward water movement. In most rangelands, ripping either has not significantly improved infiltration or cover (Branson et al. 1966; Dortignac, 1963), or has produced very short-lived benefits (Aldon and Garcia, 1972). However, Griffith et al. (1985) found ripping to be effective in increasing herbage production on shortgrass prairie in southeastern Wyoming.

Land treatment techniques must be carefully tailored to the site, with topography and soil characteristics dictating treatment types and design.

Structural Techniques

Common structural techniques used in managing runoff, sediment, and salt yields include rangeland dikes, retention plugs, retention and detention reservoirs, and gully plugs. Retention and detention structures trap runoff and sediment volumes in accordance with their design capacities. Generally, total runoff retention is required for a structure to effectively control salinity. Gully plugs usually have small retention capacities, but provide salt and sediment control by reducing erosion in active gully systems.

In addition to effectively controlling downstream impacts associated with runoff, erosion, and salinity processes, retention/detention structures may provide localized onsite benefits. Reservoirs provide water for livestock and wildlife. Even after filling with sediment they may provide a riparian-like habitat. Gully plugs, when properly located, can cause overincised channels to aggrade and, if conditions are adequate, result in the creation or restoration of streamside riparian zones (Heede, 1981). Dikes and widely spaced furrows (>5 m) usually do not increase vegetation production (Branson et al. 1966) unless they are constructed as part of a water-spreading system (Miller et al. 1969).

To control salinity, reservoirs must be designed with sufficient storage to trap all incoming runoff. While a retention structure will cease to function for salinity control after it is filled with sediments in excess of its design capacity, a proper spillway will keep the structure from failing and becoming a future source of salt and sediment. Maintenance of retention structures—either by excavating stored sediments or by increasing their height—will allow the structures to function beyond their original design life.

In highly saline areas, retention structures are usually the only practical management alternative. The feasibility of constructing these types of structures depends upon identifying secondary benefits, such as flood control, water supply, and wildlife habitat. In less saline areas, onsite benefits to water supply, vegetation production, and riparian enhancement associated with retention structures often will be greater than in highly saline areas, but mechanical treatments and vegetation management also may be feasible treatment strategies, depending upon the management objectives.

CASE STUDIES

Two BLM watershed improvement projects, both in the Colorado River Basin, are described here. Both are examples of well-planned, properly designed sediment- and salt-control projects.

Sheep Creek, Utah

Sheep Creek is a tributary to the Paria River, one of the highest sediment-producing watersheds in the Colorado Basin. Chosen in the 1950's for an intergovernmental resource conservation project, Sheep Creek is an exemplary watershed improvement project because of good interagency cooperation, primarily at the field level, and because of a well-planned mix of properly designed watershed treatments.

The Sheep Creek project area, 50.1 km^2 in size, drains mid-elevation, pinyon-juniper badlands and sagebrush on the south boundary of Bryce Canyon National Park in southern Utah. Land ownership is mixed and includes public lands managed by the BLM, Forest Service, and National Park Service, and private lands. Treatments included a concrete barrier dam on Sheep Creek at the downstream end of the project area, detention dams and dike water spreader systems on the sagebrush flats, pinyon-juniper to grass vegetation conversions, and gully checks and reseedings in the upper end of the watershed.

The barrier dam was constructed in 1961 by the Bureau of Reclamation to provide base-level control for the project area. As of April 1984, 43.9 ha–m of sediment had been trapped behind this structure and 915 m of the main Sheep Creek channel were stabilized.

BLM constructed two earthen detention dams on Sheep Creek Flat, a large sagebrush flat in the upper Sheep Creek watershed. These dams have accumulated large sediment deposits and have also been successful water control structures because their capacities are large in relation to their contributing areas.

One of the most successful treatments included a series of several hundred small gully checks constructed at the extreme upper end of Sheep Creek. These checks were installed at a very high density and successfully planted to western wheatgrass. They trapped large quantities of sediment and stabilized a downstream gully system.

Benefits realized from the Sheep Creek watershed proejcts include the following: (1) an estimated 125 ha–m of sediment trapped behind erosion and water control structures, (2) an estimated 1,000 m of main channel aggradation, (3) an estimated 6 ha of riparian vegetation established behind the Sheep Creek Barrier Dam, increasing both cover and diversity for wildlife habitat, (4) an estimated 10 km of gullies healed, (5) improved watershed cover on an estimated 200 ha, (6) reduction of flood peaks, (7) establishment of perennial flow at the Sheep Creek Barrier Dam, and (8) improved forage production (unable to quantify).

In addition, dissolved solids in Sheep Creek may have decreased in concert with the sediment reductions.

Lower Wolf Creek, Colorado

The Lower Wolf Creek project area covers 319 km^2 and represents 58 percent of the entire Wolf Creek drainage, which is tributary to the White River in northwestern Colorado. Salinity reduction was one of the management objectives for Lower Wolf Creek (U.S. Dep. Inter., 1982). Because of its large size, the Lower Wolf Creek project area was stratified into treatment units (Table 1). Treatment techniques were designed to trap and retain runoff and sediment from saline soils.

The Lower Wolf Creek project is in its third year of implementation. Initial treatments included large reservoir repair and maintenance, pit reservoirs, gully checks, and earthen retention dams. These initial treatments have been applied to the high-priority treatment units. As a step in determining the cost effectiveness of the project, benefit/cost ratios were determined for each structural treatment type, using salinity control as the primary benefit (Table 2). This information was used in the project planning to ensure that the overall mix of treatments had a positive benefit/cost ratio.

We do not have any results from the Lower Wolf Creek project at this time, as it will be several more years before the project is fully implemented. We feel this project is an excellent example of how to approach sediment and salt control in a large watershed.

SUMMARY AND CONCLUSIONS

The development of plans for salt and sediment control on western rangelands requires: (1) the establishment of resource management objectives, (2) the identification and quantification of manageable hydrologic processes, (3) the investigation of cause and effect relationships, (4) the stratification of treatment areas, and (5) the selection and evaluation of alternative treatment techniques. BLM prefers to incorporate salt and sediment control objectives as part of management plans for grazing, wildlife management, and other resource activities. When objectives cannot be met this way, techniques including vegetation management and mechanical and structural treatments may be used to control salt and sediment problems. Almost all salt and sediment control techniques influence multiple resource values. Because of the location of public lands in the significant sediment- and salt-producing river basins, BLM concentrates its control efforts in small headwater streams. Watershed projects at Sheep Creek, Utah, and Lower Wolf Creek, Colorado, are specific examples of successful salt and sediment control programs.

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Table 1.—Lower Wolf Creek watershed treatment units.

Treatment unit	% of Watershed	Description	Treatments recommended	Salt production	Priority
Mancos shale uplands	42	Mancos shale ridges, gentle to moderate slopes, sparse vegetation, and shallow soil	gully plugs, contour furrows, grassed waterways, pit reservoirs, vegetation manipulation, spreader dikes	Righ	1
Mancos alluvial	24	small drainages and dissected benches and fans at the base of Mancos shale outcrops and grassed waterways	reservoirs, spreader dikes, vegetation manipulations	high	2
Gullied alluvium	4	major gullied bottomlands	large detention reservoirs and riparian planting	low to moderate	3
Sagebrush uplands	7	upland big sagebrush sites on sandstone around perimeter of watershed	vegetation manipulation and small check dams and pit reservoirs	low	4
Pinyon-juniper woodland steep slopes	23	steep, inaccessible slopes and shallow, heavy-textured soil	none	moderate to high	5

Table 2.—Benefit/cost data by watershed treatment.

Treatment	Cost	Structures per km²	Life of project in years	Sediment storage capacity	Salt retention	Retention benefit	B/C ratio
Contour furrow	$2,350/km^2	10′ spacing	10	8,520 tonne/km^2	256 tonne/km^2	$15,972/km^2	6.80
Gully plug	$1,770/km^2	865	15	6,050 tonne/km^2	181 tonne/km^2	$11,293/km^2	6.38
Pit reservoir	$1,000 ea.	3	25	.03 ha-m	11.0 tonne	$686	.69
Check dam	$1,550 ea.	3	25	.01 ha-m	4.4 tonne	$274	.18
Retention dam	$5,000 ea.	2	25	.41 ha-m	147 tonne	$9,171	1.83
Detention dam	$60,000 ea.	0.1	50	5 ha-m	1,758 tonne	$109,682	1.83

Assumptions:
Conversion Factors:
One hectare-meter of sediment weighs 11,878 tonne
3% sediment from Mancos Shale equals the weight of salt
1 tonne of salt retained equals $62.39 benefit downstream

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SALINITY: NONPOINT SOURCE PROBLEM IN THE COLORADO RIVER BASIN

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ABSTRACT

One of the many forms of nonpoint source pollution is salinity. This pollution is causing millions of dollars in damages in the Colorado River Basin. This paper will discuss three specific areas of nonpoint source salinity pollution in the Basin and the progress we have made toward controlling it. The three areas are near the Big Sandy River in Wyoming, in the Price-San Rafael River Basins, and in the Dirty Devil River Basin in Utah. I will briefly explore the source areas, plan for controlling salinity inflow, and benefits, cost-effectiveness, and issues regarding the plan.

INTRODUCTION

I remember the time when I used to think about the Colorado River as a place for entertainment, for fishing, boating, and enjoying the wildlife in the area. I still think of the Colorado in those pleasant terms, but now I also think in terms of the growing invisible water pollution problem. One of the many forms of pollution is salinity—salts. Salts are minerals or dissolved solids—sodium, chlorides, sulfates, and others—that are picked up by the river. By the time the Colorado reaches Hoover Dam, it is carrying about 8.1 millions tonnes (9 million tons) of salt annually, and causes millions of dollars in damages in the Lower Colorado River Basin.

In this paper I will provide a brief background of the overall problem in the basin and the progress toward controlling it. I will also discuss briefly three specific nonpoint sources.

BACKGROUND

About half of the present salt pollution in the Colorado River comes from natural sources, including mineral springs and geysers. The salts originate from water seeping through ancient marine deposits and saline soils, which are washed into streams. The balance comes from the concentrating effect of man's use of water for irrigation, municipal and industrial use, and reservoir operation.

The Colorado River at its headwaters in the mountains of Colorado has a salinity of only about 50 mg/L. The salinity concentrations progressively increase downstream as a result of the use of water and salt contributions. In 1982, the salinity averaged 825 mg/L at Imperial Dam, the last major diversion point on the Colorado River in the United States. The salinity in the river does fluctuate, however. Record high flows in 1983 and 1984 diluted the salinity levels at Imperial to 710 mg/L and 670 mg/L, respectively (see Fig. 1). While these higher flows and diluting effects will give us additional time to seek more cost-effective solutions for salinity control, normal flows will increase the river's salinity levels to the 800–900 mg/L range in 4-5 years. Without control measures, the concentrations are projected to increase to over 1,000 mg/L by the year 2020.

Salt pollution affects more than 10 million people and 400,000 ha (1 million acres) of irrigated farmland in the United States. Economic losses associated with municipal use occur primarily from increased water treatment costs, accelerated pipe scaling and appliance wear, and increased soap and detergent needs. Some people prefer bottled water or softened water to the taste of the salty water. The Environmental Protection Agency recommends that we drink water with no more than 500 mg/L of total dissolved solids.

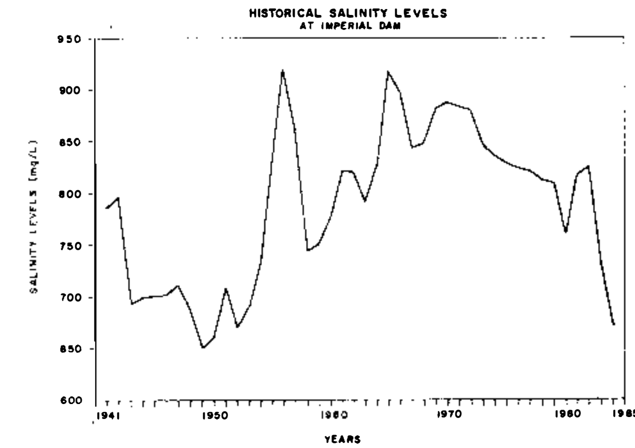


Figure 1.—Historical salinity levels at Imperial Dam from 1941 through 1984.

For irrigators, higher concentrations decrease crop yields, alter crop patterns, and result in higher leaching and drainage requirements, and higher management costs. Agricultural losses begin when salinity levels of applied irrigation water reach 700 to 850 mg/L, depending upon soil conditions and type of crop grown.

Total annual damages to the Lower Colorado River Basin water users are approximately $561,000 for each rise of 1 mg/L in salinity concentration at Imperial Dam. Economic losses are estimated to be about $90 million annually. That does not include the undetermined economic impact on Mexico.

In June 1974, Congress enacted the Colorado River Basin Salinity Control Act, P.L. 93-320. Title I of the Act authorized construction of the Yuma desalting complex and other features to provide better quality water to Mexico in accordance with Minute 242 of the International Boundary and Water Commission Agreement.

Title II, the Colorado River Water Quality Improvement Program, directed the Secretary of the Interior to expedite completion of planning reports on 12 salinity control units and authorized the construction of four selected units. Under a cost-sharing approach, one-fourth of the construction costs of the authorized units were to be provided by Upper and Lower Basin funds, with revenue obtained from the sale of hydroelectric power.

P.L. 98-569, signed on Oct. 30, 1984, amends P.L. 93-320. This legislation amends, enhances, and updates the 10-year-old salinity control act. It is the culmination of a 2½ year effort by the Colorado River Basin States working in close cooperation with Federal agencies.

The Colorado River Basin Salinity Control Forum, representing the seven Colorado River Basin States, believes that the act as now amended provides the authority for the pursuit of salinity control measures that will put in place the necessary salinity controls on the river through the year 2000. It will ensure, if implemented, the compliance with the numeric criteria (standards set on the lower main stem) at least through the year 2005.

To meet the salinity standards now set for the basin, up to 1 million tons of salt per year must be removed from the river system by the turn of the century. This level of salt removal will prevent salinity concentrations from exceeding the numeric salinity criteria while the basin States continue to use and develop their basin water supplies. The criteria, set in terms of milligrams per liter of total dissolved solids, are essentially a nondegradation standard based upon 1972 historical data. The maximum salinity concentration level allowed at Imperial Dam is 879 mg/L (See Table 1.)

The Bureau of Reclamation has been designated to lead the Federal effort to reduce the salinity in the river system. The Colorado River Basin Salinity Control Forum works with Reclamation, the Department of Agriculture, and other Federal agencies to implement controls to maintain the salinity levels in the Colorado River. Both structural and nonstructural measures are necessary to intercept and control sources of man-caused and natural salt load.

Under the Colorado River Water Quality Improvement Program, construction will occur on a priority basis so that the most cost-effective measures will be implemented to meet program goals. To avoid the high energy costs of desalination plants or vast areas of evaporation ponds, other beneficial use concepts are being considered.

Reclamation has investigated possible beneficial uses of the saline water. In a September 1981 Special Report, entitled "Saline Water Use and Disposal Opportunities," Reclamation identified other salinity control strategies that appear both cost effective and environmentally acceptable. Several States are considering options using saline water locally in powerplant cooling towers.

Different ways of solving the problem depend partly upon the way the salt enters the river. More than a third of the salt enters the river from irrigation sources.

Irrigation source control would reduce salt loading by improving irrigation practices that currently leach salts from marine shales and other saline deposits. The Grand Valley Unit in Colorado is one major example of irrigation source control where construction by both Reclamation and Soil Conservation Service has been going on for several years. Reclamation estimates that distribution systems and on-farm practices in Grand Valley, Lower Gunnison, and McElmo Creek Units in Colorado and the Uinta Basin Unit in Utah could be improved to reduce the river's salt load by up to 1 million tons per year.

Another source of salt loading involves identified point sources such as mineral springs, abandoned oil wells, and geysers. Paradox Valley and Meeker Dome Units in Colorado are point sources. Paradox Valley Unit is under construction, and abandoned oil wells in the Meeker Dome Unit were successfully plugged during verification studies.

Control opportunities from the third source involve diffuse sources of salt, or what we are discussing today as nonpoint sources. Diffuse source control measures include watershed management, land treatment, some irrigation improvements, and the collection and disposal of poor quality streamflows. Investigations of these diffuse units are examining a combination of irrigation improvements, vegetation and watershed management, and selective withdrawal and disposal of poor quality streamflows.

Table 1.—Salinity numeric criteria for the Colorado River.

Station	Annual flow-weighted average
Below Hoover Dam	723 mg/L
Below Parker Dam	747 mg/L
At Imperial Dam	879 mg/L

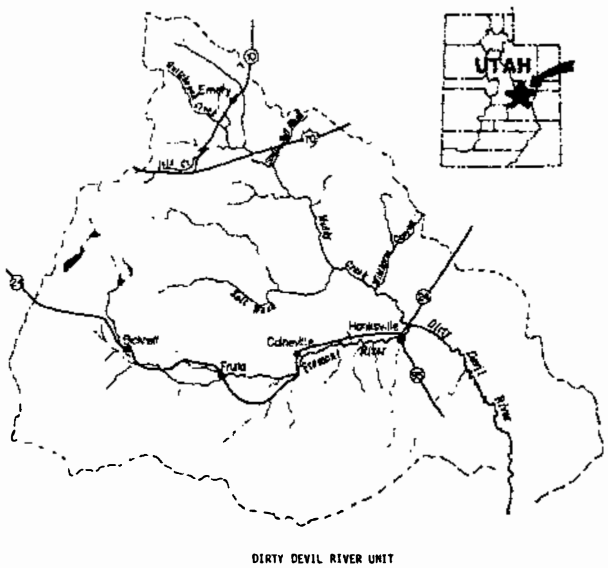


Figure 2.—Dirty Devil River Unit location map.

The three diffuse nonpoint sources are the Big Sandy River in Wyoming, the Price–San Rafael River Basins in Utah, and the Dirty Devil River Basin, also in Utah. Of interest here are the source areas, the plans for controlling the salinity inflow into the Colorado River, the benefits to be derived as well as the cost effectiveness of each plan, and what, if any, current issues affect the plans.

DIRTY DEVIL RIVER UNIT

The Dirty Devil River contributes approximately 170,500 tonnes (155,000 tons) of salt annually to the Colorado River. The preferred plan would reduce the salt load of the Colorado River by approximately 22,600 tonnes (20,600 tons) per year. (See Fig. 2.)

The Dirty Devil River Unit is located in south central Utah. The unit area is sparsely populated, with over 75 percent of the land administered by the Federal Government. Two geologic formations contribute significant amounts of salt to the Dirty Devil River drainage—the Mancos Shale and Carmel Formations. The Mancos Shale is responsible for the salinity increase in the irrigated area near Emery and along the lower reaches of the Fremont River.

The Carmel Formation is the salt source in Emery South Salt Wash and Hanksville Salt Wash. Saline springs feeding the washes result from water percolating from the underlying Navajo Sandstone aquifer through the salt-bearing Carmel Formation and emerging through surface fractures.

After evaluating numerous plans, one strategy emerged. This preferred plan consists of collecting saline spring water in Hanksville Salt Wash and Emery South Salt Wash and disposing of it by deep-well injection. Saline water would be collected by pumping at the rate of .0825 cubic meters (2.75 cubic foot) per second from shallow wells in the aquifer. This water would be filtered and chemically stabilized after which it would be injected into a geologic formation, the Coconino Sandstone, where it would be stored indefinitely, isolated from any freshwater aquifer.

This would decrease the salt load by approximately 20,600 tons annually, reducing salinity at Imperial Dam by about 1.88 mg/L. The total capital cost of the project is expected to be approximately $12 million. In terms of total costs per unit removed, the cost effectiveness is approximately $97 per ton of salt removed or $1,063,000 per mg/L at Imperial Dam. This cost effectiveness level can be compared to other controls now under construction which range from $70 to $90 per ton.

This preferred plan will be studied as the planning report/environmental statement is prepared. Advance planning would take approximately 2 years and construction about 3 years.

Several unresolved issues remain:

1. Verification of the site-specific hydrologic and geologic conditions of the Coconino Sandstone.
2. Environmental mitigation because the unit plan would dewater a section of Hanksville Salt Wash.
3. The question of beneficial use of saline water. The State Engineer has reviewed the plan but has reserved judgment until water rights have been applied for.
4. Obtaining State and EPA approval for injection into the Coconino Sandstone. Completion of further site-specific study, including drilling a test well, will be necessary to address this issue.

PRICE–SAN RAFAEL RIVERS UNIT

The Price–San Rafael Rivers Unit is in east-central Utah, 192 km (120 miles) southeast of Salt Lake City. The watersheds of the two rivers drain into the Colorado River via the Green River and add about 430,000 tons of salt annually to the Colorado River system. (See Fig. 3.) Over 70 percent of the land in the basin is administered by the Federal Government. Two percent of the land is in irrigated alfalfa and feed crops.

After evaluating the salt sources in the area, a preferred plan has been selected: improve winter stockwater practices by lining stockwater ponds to reduce seepage. Additional stockwater ponds would be provided and existing ones would be improved by enlarging and lining. In some areas, existing domestic water systems could be expanded to provide supplemental supplies to stockwater users.

The improved winter stockwater practices could reduce the salinity at Imperial Dam by about 19,800 tonnes (22,000 tons) or 2.2 mg/L and the capital cost would be approximately $8 million. The cost effectiveness of this plan would be approximately $304,000 per mg/L or about $31 per ton, which is cost effective compared to other unit plans.

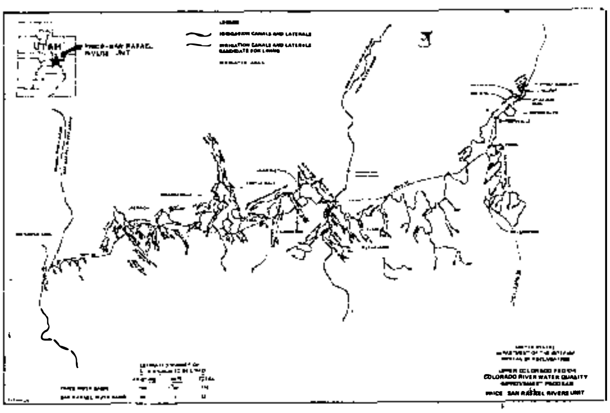
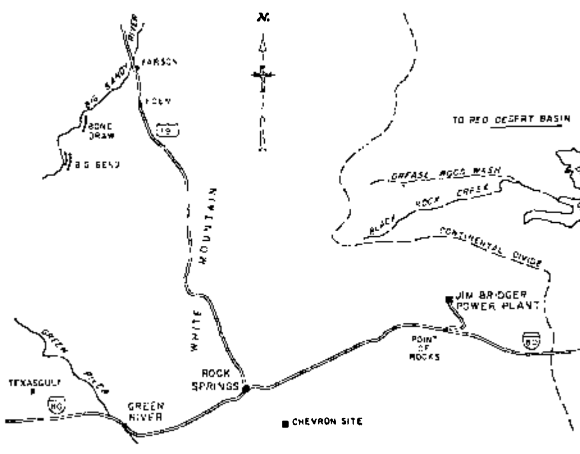


Figure 3.—Price–San Rafael Rivers Unit location map.



BIG SANDY RIVER UNIT

Figure 4.—Big Sandy River Unit location map.

BIG SANDY RIVER UNITS

The Big Sandy River Unit is in southwestern Wyoming and includes the lower Big Sandy River, a tributary of the Green River in the Upper Colorado River Basin. This study is specifically directed toward formulating plans to reduce salt pickup from seeps and springs along a 41.6 km (26-mile) reach of the Big Sandy River west of Eden, Wyoming. (See Fig. 4.)

Investigations indicate that saline seeps, totaling some 1.11 cubic meters (37 cubic feet) per second, surface along the seepage area. The salinity here varies from 1,000 mg/L to 6,000 mg/L along the Big Sandy River with a total annual contribution of more than 147,000 tonnes (164,000 tons) of salt to the river, increasing salinity at Imperial Dam by 16.6 mg/L. Indications are that salt is picked up by deep percolation from irrigation water contacting the shale of the Green River Formation and eventually seeping into the river.

The Soil Conservation Service studied on-farm solutions to the salinity problem. Reclamation focused on off-farm solutions and identified various ways to intercept the springs and seeps and transport, treat, and use or dispose of the saline water.

The recommended Reclamation plan would collect a total of .498 cubic meters (16.6 cubic feet) per second of saline wells near the spring and seep area, pumping it though a pipeline to the proposed Chevron Chemical Co. fertilizer plant near Rock Springs, Wyoming. However, Chevron has deferred expansion plans and the recommended plan is no longer viable.

A new plan being developed would collect saline water from a collector well field and transport it to the Divide Basin for disposal. This plan, proposed only as an interim solution, is not a beneficial use of the water.

Wyoming has been an active partner throughout the study, with Reclamation working with them to develop alternatives. Reclamation has reformulated alternatives and will concentrate on disposal in the Divide Basin and use of saline water at the Jim Bridger Powerplant or Chevron chemical plant. A consultant is currently studying the feasibility of using saline water for cooling at the powerplant, and the results of that study will be used in evaluating these alternatives.

The SCS is evaluating a low head pressure on-farm sprinkler system. The State will evaluate both SCS's and Reclamation's studies and will ultimately recommend a course of action to the Federal agencies.

The draft planning report/environmental impact statement is scheduled to be filed with the EPA in June 1986;

however, this will depend on the development and evaluation of the overall recommended plan of action.

SUMMARY

We have three units under construction, and the Dirty Devil River, Price–San Rafael Rivers, and Big Sandy River are three of the 12 Reclamation units currently under study in the Colorado River Water Quality Improvement Program. As technology changes in the development of powerplant cooling or other beneficial use opportunities, the development potential of specific units will improve. A long-range program is being developed for the next 20-25 years, one that will implement the most cost-effective units needed to maintain the numeric criteria set for the river system.

CONTINUOUS SALINITY STATION MONITORING IN THE COLORADO RIVER BASIN BY THE UTAH BUREAU OF WATER POLLUTION CONTROL

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ABSTRACT

The objectives of our salinity monitoring program are to characterize the Colorado River Basin waters by determining the total dissolved solids loadings entering and leaving Utah and the relative contributions from major basins. A network of nine continuous recording salinity stations collect temperature and specific conductance data. The continuous recording devices consist of Hydrolab Datasondes* (registered trademark of Hydrolab Inc.) are programmed and standardized in Salt Lake City before they are distributed to their specific field locations. Each salinity station is visited monthly to replace the Datasondes* and to collect ambient water quality information. The data from the sondes are read and edited into a computer storage file. The conductivity data, along with chemistry and flow data are then combined to determine loadings.

INTRODUCTION

The objectives of the Bureau of Water Pollution Control's salinity monitoring program are to characterize the Colorado River Basin waters by determining the total dissolved solids loadings entering and leaving Utah and to determine the relative contributions from major drainage basins.

The Colorado River Basin Salinity Control Forum was created in 1973 to maintain salinity at or below the levels found in the lower Colorado River mainstem as of April 1972. The Forum consists of water resource and water quality representatives appointed by the governors of each basin State. Most Forum members are also members of the Colorado River Salinity Control Advisory Council created by P.L. 93-320 to advise the Secretary of Interior, Secretary of Agriculture, and the Administrator of Environmental Protection Agency on salinity issues.

Salinity standards, including numeric criteria and salinity control implementation plans, were produced by the Forum in 1975 and revised in 1978, 1981, and 1984. This plan and revisions have been adopted by each of the seven basin States as part of their water quality standards and have been approved by the Environmental Protection Agency. The Forum reviews the standards, including the numeric criteria and plan, each year. The plan is brought up to date as appropriate but at least once every 3 years. The numeric criteria are revised only when necessary as agreed by the Forum States.

The Forum plan of implementation is comprised of a number of Federal and nonfederal measures to maintain the adopted salinity criteria of 723 mg/L below Hoover Dam, 747 mg/L below Parker Dam and 879 mg/L at Imperial Dam (Utah, 1982a).

The Utah Bureau of Water Pollution Control maintains a network of ambient monitoring stations in the Colorado River Basin. Grab samples and field observations are taken at designated sampling stations, nine of which are continuous monitoring salinity stations (Table 1, Fig. 1) (Utah, 1982b). Continuous monitoring salinity stations are important because they can record the periodic storm events and resulting shock loads common to southern Utah. Salinity stations are strategically located to monitor salinity entering and leaving Utah and salinity contributions from major drainage basins. The station on the Green River at Dinosaur National Monument and that on the Colorado River at Cisco monitor salinity entering Utah, while the rest have been located at the bottom of major drainage basins to record salinity contributions from their respective basins. Two stations, Virgin River above First Narrows and Colorado River below Glen Canyon Dam, were installed in 1984. The Ashley Creek and Dry Gulch stations were installed in 1981 and the remainder have been in operation since 1976.

METHODS AND MATERIALS

When the program began in 1976 each salinity station consisted of a Hydrolab Surveyor unit coupled to a Ball Brothers recording device housed in a weather- and vandalproof shelter. Temperature and conductivity measurements were recorded every 30 minutes onto a cassette tape. The stations were serviced biweekly by changing batteries and installing an unused cassette tape. The current continuous recording salinity stations collect hourly temperature and specific conductivity data. These stations consist of Hydrolab Datasondes (a registered trademark of Hydrolab, Inc.) housed in permanent, protective 6-inch diameter steel pipes adjacent to U.S. Geological Survey gauging stations (Hinshaw, 1985). State personnel determine stream flows where U.S. Geological Survey flow data are not available.

The sondes are standardized, programmed and calibrated in Salt Lake City before they are distributed to their specific field locations. Sonde servicing includes a thorough examination, cleaning, and installation of fresh batteries. The sondes are calibrated using a known conductivity solution prepared by the State Health Laboratory.

Each salinity station is visited monthly to replace sondes and to collect ambient water quality samples. The samples and sondes are brought back to Salt Lake City for routine chemical analyses and data retrieval. The data from the sondes are loaded onto a WANG personal computer floppy disc, edited, and transferred to the mainframe computer (Judd, 1985).

The editing consists of adjusting the conductivity readings recorded by the sondes; to do this, conductivity data from the ambient water quality samples are compared with field readings. Total dissolved solids (TDS) data from the ambient water quality samples are used to develop a TDS/conductivity ratio for each salinity station based on its drainage basin chemical characteristics. The TDS/conductivity ratio is combined with flow data from U.S. Geological Survey or from Bureau of Water Pollution Control to determine loadings at each station.

Currently, the Bureau of Water Pollution Control has limited resources for data analyses by computer technol-

Table 1.—Salinity Stations.

Storet #	Site	Latitude	Longitude
493027	San Rafael River at Chaffin Ranch Bridge	38° 45′ 32″ N	110° 08′ 24″ W
493165	Price River at Woodside	39° 15′ 50″ N	110° 20′ 45″ W
493414	Dry Gulch Creek at U-132 road crossing	40° 15′ 50″ N	109° 51′ 31″ W
493721	Ashley Creek above confluence with Green River	40° 20′ 30″ N	109° 21′ 54″ W
493790	Green River at Dinosaur National Monument	40° 24′ 34″ N	109° 14′ 05″ W
495002	Virgin River above First Narrows	37° 01′ 05″ N	113° 39′ 58″ W
495200	Colorado River below Glen Canyon Dam	36° 56′ 12″ N	111° 29′ 00″ W
495430	Dirty Devil River above confluence with Poison Spring Wash	38° 05′ 50″ N	110° 24′ 27″ W
495849	Colorado River at Dewey Bridge crossing near Cisco, Utah	38° 48′ 39″ N	109° 18′ 11″ W

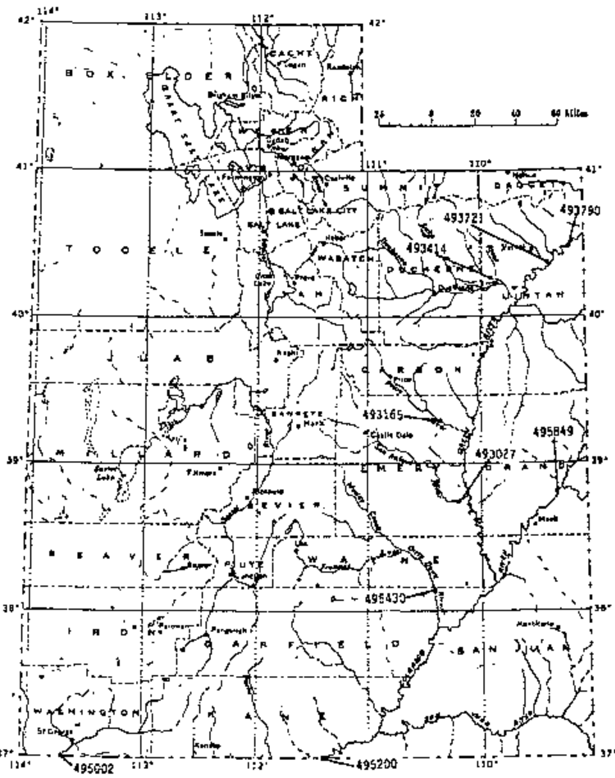

Figure 1.—Location map, continuous monitoring salinity stations. Sites are identified by Storet number.

ogy. Previous attempts to analyze the data have been by hand manipulation, requiring a great deal of time and effort.

RESULTS AND DISCUSSION

Nine continuous salinity monitoring stations are operating in Utah. Two stations located on the Virgin River and below Glen Canyon Dam have been installed recently, resulting in very little data for analysis. The following discussion covers the problems, data, and locations of the seven stations.

The abundance of conductivity data available for analysis would be overwhelming if the daily flow data correlation was done by hand. Because of the limited computer analysis capability, the grab sample data must serve as both the quality control benchmark, and the data base to which generalized flow data may be applied. Unfortunately, this eliminates the ability to document many unusual flow and salt-loading events such as flash flooding and dry periods. The accuracy of the averaging still reflects the general activity of the stations. Insufficient grab sample data exist to establish any type of yearly trends in salinity because they appear to be subject to the quantity of water available during the year.

The Ashley Creek drainage basin includes 168,074 ha. The salinity contributions to this drainage are from agricultural return flows, energy exploration activities, and the natural geology.

Ashley Creek is dewatered at the mouth of Dry Creek Canyon by irrigation diversions, resulting in the down-gradient water monitored by the salinity station being mostly irrigation return flow. The daily averages are useful for the hydrologic/mineralogic cycle of the stream. In 1981, only 8 months of data were available, February through September. The average daily flow for water year 1982 (February–September) was 154 percent of 1981. Comparing the 1981 data (February–September) with 1982 data of the same months, the 1982 average daily salt load of 500 metric tons/day was 10 percent lower than the 1981 salt load of 552 metric tons/day (Ellis, 1984). The flows in Ashley Creek peak during spring runoff. Because the flows during the 1982 water year were greater than in 1981, the resulting greater dilution reduced salinity.

The station located on the Colorado River near Cisco records the salinity contributions from the Colorado and Dolores Rivers entering Utah. This station has been in operation since 1976 except when flooded for short periods during some extremely high-water years. As a result of the flooding, the station was moved downstream .5 mile to the Dewey Bridge. Salinity contributions in the Colorado River are from agricultural, industrial, and mining activities. With data available for 1980, 1981, and 1982, February 1981 indicates the least salt load at 175,086 metric tons while April 1980 reflects the highest load at 485,704 metric tons. Flow and salt load peaks are noticeable only for the 1980 and 1982 runoff periods. The 1981 runoff produced flows and salt loads similar to the autumn peak of that year (Ellis, 1984).

The Dirty Devil River drainage represents a unique area in the Colorado River system. Most of the salinity contributions are natural with very little from agricultural or industrial sources. The drainage area includes 3,074,655 ha with most nonpoint pollution resulting from runoff and erosion from sparsely vegetated Federal (public) lands. The Dirty Devil River is the least stable of all the continuously monitored rivers in terms of both salinity and water flow. No-flow periods are common during the summer. High flow peaks occur not in the spring, but in the fall after upstream irrigation use has ceased and as a result of thunderstorm activity.

The 2 years with a no-flow period showed the high peak for both flow and dissolved solids loading as occurring directly after the no-flow period. September of 1980 showed 155,854 metric tons of dissolved solids carried by the river following a 24 day no-flow period. This load exceeded the next highest load (August 1982) by 72 percent. The next no-flow period extended for 51 days. Two weeks after the flow of the river resumed, the third largest monthly peak of flow and salinity occurred. Spring peaks appeared to be rather mild when compared to the late summer–early autumn peaks.

These peaks can also be viewed from their contribution to the total amount of dissolved solids carried in the river during the year. The September peak carried 58 percent of the 1980 salinity load. The September peak carried a 36 percent share of the 1981 load, while the August peak carried 28 percent of the total salinity load for 1982. Average concentration of total dissolved solids for each year is as follows (Ellis, 1984):

1980	2,028 mg/L
1981	1,879 mg/L
1982	2,101 mg/L

The Dirty Devil River is located in a semiarid region and is dry during summer months; however, peak flows occasionally result from sudden storm events. This may account for the high flows during late summer and early fall, especially since 1981 through 1983 have had record breaking precipitation.

Dry Gulch is unique. The stream exists because of irrigation return flows. The monitoring station is vital because the Bureau of Reclamation and the Soil Conservation Service have targeted the drainage area for salinity control projects. The success of these projects will be shown in the data gathered by this station, but the Dry Gulch station has been difficult to assess. Problems with location, equipment, and flow have resulted in many months of unreliable data. Bureau personnel have solved many of these problems, resulting in better data gathering and compilation.

The salinity station on the Green River at Dinosaur National Monument monitors the salinity contributions coming into Utah from the Green and Yampa Rivers. Flaming Gorge Dam controls flows at this station, resulting in standard runoff peak flows and daily fluctuations from electrical power demands. This station records the lowest values of salinity of all the stations. This station has had few problems, resulting in good data since its installation in 1976. The average dissolved solids concentration for 3 years of data is as follows (Ellis, 1984):

1980	339 mg/L
1981	393 mg/L
1982	329 mg/L

The Price River drainage area is 486,066 ha. A large percentage of the land area is federally owned and is used for livestock grazing. The sparse vegetation contributes to increased salinity levels from overland flows. The large size of these range areas and limited ability to sustain vegetation offer little opportunity for improvement. The Price River station has limited data available because of vandalism and equipment breakdown. Problems have resulted because of probes being silted and because accessibility encourages damage from the curious. The available data showed an increase of dissolved solids in the river during October 1981. The spring of that year showed little or no influence from runoff at the monitoring station. The Price River experienced increased flow and dissolved solids loading in the spring of 1982 as well as later in the summer of the same year. More data are required to make any real predictions on the Price River.

The San Rafael River drainage area is 622,488 ha. Most of the area is sparsely vegetated and offers little opportunity for improvement. The San Rafael River area is semiarid resulting in no-flow periods during the summer months. The station has had silting-in and flooding problems. This station was recently moved from its old location at U-24 highway crossing to 3 miles above the mouth of the San Rafael River. The flow and dissolved solids for the San Rafael River showed primary and secondary peaks in a pattern unique for the monitored streams of southern Utah. The primary peaks of dissolved solids for 1980 and 1982 occurred in the summer. The summer of 1981 recorded the lowest value for salt loading. Secondary peaks for 1980 and 1981 occurred in the fall. This is similar to the pattern of other southern Utah streams where summer irrigation cessation allows water to remain in the stream. One more secondary peak occurred during February and March of 1980. The average total dissolved solids concentration for each year follows (Ellis, 1984):

1980	1,487 mg/L
1981	3,068 mg/L
1982	2,068 mg/L

CONCLUSIONS

In summary, from available data, the profile of streams in the State vary from the northern and the southern portions with respect to seasonal loads of dissolved solids. Northern streams appear to have a definite spring/summer runoff peak. The southern streams appear to have two definite periods when flows and salt loads can peak—spring and fall. In the case of the Dirty Devil River, only a fall peak was observed. The reason for this flow pattern is unclear. It may be the result of 3 years of unusually high precipitation. More analyses are needed over longer periods of record to substantiate the findings.

These data should be considered as only rough indicators of actual salt loading. More accurate daily computations are necessary in monitoring the unstable streams in the State. Such computations require improvement in the quality of continuous data recording for such troublesome streams as Price River and a computer analysis to synthesize the daily salinity and flow data. High runoff has decreased total dissolved solid concentrations but increased flows have increased total loadings to the Colorado River drainage.

The State of Utah shows great potential for establishing accurate salt-loading information. The Bureau is currently hampered by budget and personnel constraints, along with inadequate computer facilities. When these problems are solved, the State will be able to provide better salinity data and information to all interested individuals and agencies. Salinity will always remain a problem in Utah. The State of Utah will continue to monitor and analyze salinity information with the resources available.

ACKNOWLEDGEMENTS: Several people helped with this report. I would like to express appreciation to Russell Hinshaw and Harry Judd for their assistance, and to Mark Ellis for his interpretation of the sampling data at the salinity stations.

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SALINITY CONTROL IN THE GRAND VALLEY OF COLORADO

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ABSTRACT

Half the salt annually entering the Colorado river system comes from manmade influences, and most comes via irrigation seepage and on-farm percolation. To reduce the water entering Imperial Dam by 1 mg/L, nearly 11,000 tons need to be prevented from entering the river. A U.S. Department of Agriculture and Department of Interior program attempted to reduce these loads by 50 percent through lining and piping the irrigation systems and improving on-farm practices. The project, scheduled to run through the year 2000, is 10-20 percent complete. Projections indicate salinity in the Imperial Dam should have already decreased by 4.3 mg/L.

INTRODUCTION

The Grand Valley in west central Colorado contributes about 522,000 metric tons (580,000 tons) of salt annually to the Colorado River system. It is estimated that at least 50 percent of the river's total salt load comes from manmade influences. In both the United States and Mexico, the increased salinity in the water supply causes significant agricultural and urban economic damages to downstream water users. Salts are brought into the river system by subsurface return flows percolating through saline soils and fractured saline shales. Of the total 522,000 metric tons (580,000 tons), about 475,200 metric tons (528,000 tons) come from irrigation delivery system seepage and on-farm percolation losses. Surface runoff, deep percolation from recreation reservoirs, seepage from utility canals, and other sources contribute the remaining salt load of 46,800 metric tons (52,000 tons).

To reduce the salinity concentration at Imperial Dam by 1 mg/L, an estimated 9,900 metric tons (11,000 tons) of salt must be prevented from entering the river. The annual economic damage to downstream water users in the Lower Colorado River Basin States is estimated to be $561,000 per mg/L for concentrations ranging between 875 and 1,225 mg/L at Imperial Dam. Not included are economic damages to Mexican water users, which would add significantly to this dollar amount.

In 1979 and 1980, the Federal government, through the U.S. Department of Agriculture (USDA) and the U.S. Department of the Interior (USDI), implemented programs in the Grand Valley to reduce the seepage and associated salt loading. The program assists local water users to line or pipe delivery systems and improve on-farm irrigation systems and irrigation water management. Planning and application responsibilities of the program are divided, with the USDI lining and piping off-farm irrigation canals and laterals and the USDA helping landowners improve on-farm irrigation systems and management.

The program goal is to reduce seepage and associated salt loading by at least 50 percent. The estimated improvements to irrigation systems consist of lining 72 km (45 mi) of off-farm delivery canals; piping 704 km (440 mi) of off-farm delivery laterals; piping or lining 1,056 km (660 mi) of on-farm ditches; and installing improved irrigation systems, including irrigation water management, on 21,200 ha (53,000 acres).

PROBLEM

The Colorado River has eroded the Grand Valley into the Mancos Formation, a sequence of marine shale about 1,200 m (4,000 ft) thick that contains a high percentage of salts and gypsum. The salt crystals are commonly found in open joints and fractures. The Mancos Formation is impervious at depth, but the weathered zone near the surface transmits water along joints, fractures, and bedding planes.

An aquifer exists within the Mancos Formation between the Government Highline Canal and the Colorado River. Recharge of this aquifer system occurs from canal, lateral, and on-farm ditch seepage, or where irrigation waters percolate into the zone through vertical jointing in the shale.

Essentially all irrigated land in the valley is underlain by Mancos Shale. Salt types present here are mostly calcium sulfate. Since many of the soils are derived from the Mancos, they exhibit chemical properties similar to that of the shale. Addition of salts to the river system is not the only cause of increased salinity concentrations. Removal of water by phreatophytes and field crops increases the salinity concentration of return flows. Also, removing better quality water in the Upper Colorado River Basin reduces the dilution effect on the waters of the downstream reaches.

AUTHORIZATION

The Grand Valley Unit was authorized for construction by the Colorado River Basin Salinity Control Act of 1974 (P.L. 93-320) as part of a basinwide program for enhancing and protecting the quality of water available in the Colorado River for use in the United States and the Republic of Mexico. Title I of the Act was directed toward controlling the salinity of river water below Imperial Dam. Title II, directed toward salinity control in the United States above Imperial Dam, authorized the construction of the Grand Valley Unit and three other units.

The USDA on-farm program in the Grand Valley and the Uinta Basin of Utah was planned and implemented with existing authorities. The program took effect in October 1979 when Congress allocated $1.7 million to the Grand Valley from the Agricultural Conservation Program (ACP), administered by the Agricultural Stabilization and Conservation Service. Funding at that level under that authority has continued since with ACP rules and regulations controlling administration of the salinity control program. However, the ACP program could not continue its work nationally and also support the growing salinity control program. Moreover, the ACP regulations limited the pace at which salinity control practices could be installed on individual farms. Therefore, recognizing the need to accelerate the salinity control program, Congress passed P.O. 98-568, amending P.L. 93-320 and authorizing USDA to establish a new program for salinity control based on the voluntary participation of private landowners.

USDI Program

The USDI portion of the program was planned by the Bureau of Reclamation in two stages, primarily to use information from Stage One in the planning of Stage Two. Stage One construction began where data could be gathered to assess effects of initial development and where environmental impacts were not believed to be significant. Planning on Stage Two took place concurrently. Stage One construction, which covered about 10 percent of the Grand Valley, began in October 1980 and was essentially completed in April 1983; it included concrete-lining 10.9 km (6.8 mi) of the Government Highline Canal and consolidating 54 km (34 mi) of open laterals into 38 km (24 mi) of pipe laterals.

Salinity monitoring data indicate that seepage and salt loading have declined in the Reed Wash study area, a hydrologically closed basin north of Loma, Colorado. Stage One results indicate that salt loading has decreased by about 13,000–22,500 metric tons/yr (20,000–25,000 tons/yr) or 1.8–2.3 mg/L at Imperial Dam. A moss and debris removal structure installed at the beginning of the lined portion of the Government Highline Canal consists of three trash rakes to remove most of the trash, weeds, and debris. This systemwide removal has solved most of the problems; however, additional design modifications to the turnouts and meters are planned for Stage Two, based on the experience in Stage One.

A problem developed in Stage One that affected planning on Stage Two concerning cracks in the concrete-lined canal. The concrete lining of Stage One, completed during the winter of 1980–1981, is 6.35 cm (2½ in) thick, unreinforced, and placed on compacted embankment with a thickness of at least 60 cm (2 ft). During the first 2 years following construction, very few cracks appeared in the concrete; however, in the winter of 1983–84, extensive cracking occurred. A freeze–thaw action of the canal water is believed to be the primary cause of the cracks. The existing cracks will probably be widened and extended by further freeze–thaw and by hydraulic uplift. The plan for Stage Two is to membrane-line the Government Highline Canal and replace existing open earth laterals with pipe.

Based on expected wildlife habitat losses in Stage One and Stage Two, compensatory measures are to include acquiring more than 800 ha (2,000 acres) of riverbottom land along the Colorado River.

USDA PROGRAM

Since the USDA on-farm program began, about 232 km (145 mi) of on-farm delivery systems have been lined or piped, and improved irrigation systems have been installed on 3,880 ha (9,700 acres). The decrease in annual salt loading as a result of these improvements is about 24,300 metric tons (27,000 tons) or a reduction of 2.5 mg/L in salinity concentration at Imperial Dam.

The types of irrigation systems being installed include: underground delivery pipelines with other gated pipe or concrete-lined ditch distribution systems for surface irrigation, sprinkler systems where adequate gravity pressure exists, or drip–trickle irrigation on specialty crops. Many of the surface-irrigated fields are also land leveled to allow a more uniform water distribution. A number of recently developed semiautomated irrigation systems have been used successfully. Cablegation, ported concrete ditches, and some farmer-developed automated valves have been readily accepted.

In an attempt to incorprate more management into the irrigation system, commercially available automatic water-switching valves were instrumental on a number of early systems. Mandatory automation in 1979 generally met with rejection from farmers because of a lack of operator understanding and poorly developed technology.

Research and development on automating irrigation systems is progressing; several automated systems are now being used successfully. Cablegation, an irrigation system developed by the Agricultural Research Service in Kimberly, Idaho, is being tested on several farms in the Grand Valley. Farmer acceptance has generally been excellent, with several landowners working toward converting their operations entirely to a cablegation system. Cablegation owners report approximately 30 percent less water usage and higher crop yields compared to earlier irrigation practices on those fields. A skate gate system for ported concrete ditches, similar to cablegation, has also been successful.

Further research and testing of automatic controls is needed for valves in pipelines and gated pipe to control water flows. Some of the design and much of the field testing has been done by local farmers. A local grower has developed an automatic valve control for gated pipe using a rechargeable electric drill and timers that automatically change water sets on his fields. This type of commitment to progress is necessary for development and application of field-reliable automation.

The key to a voluntary Federal program on private land is landowner acceptance. Generally, the irrigation systems have performed well for the landowners. The installed irrigation systems provide an effective tool to better control irrigation water. In addition to the reduced seepage from unlined farm ditches, more precise and uniform water distribution with accurate measurement is possible with new systems.

The on-farm irrigation improvement is a two-stage process. First, the installed irrigation system reduces seepage from the unlined farm ditches and provides the landowner with a manageable system to uniformly apply the irrigation water. Secondly, followup technical assistance helps the farmer apply the amount of water needed in a timely manner. The expected salinity reduction benefits are divided almost equally between the improved system and better water management; gains are needed in both of these areas for a successful program.

MONITORING & EVALUATION

Aggressive monitoring and evaluation programs assess and quantify the actual salinity reduction benefits of the combined cooperative effort between the Federal government and the water users. In the Stage One area, Reclamation is monitoring ground water levels and canal inflow and outflow. The quality of canal water and the quality and quantity of Reed Wash outflow are also being recorded.

The SCS has implemented an on-farm monitoring and evaluation program. Electronic flow recorders and remote weather stations gather the field information to assess seasonal irrigation performance. Irrigation monitoring is currently ongoing on 16 sites, with four additional sites scheduled for installation during the summer of 1985.

The effects of Stage One on fish and wildlife resources were monitored by the Colorado Division of Wildlife between 1981 and 1984. Since changes to wildlife habitat were expected, replacement of endangered habitats was planned for both Stage One and Stage Two. The monitoring by the Division documented that significant changes to wildlife habitats occurred in the zones along canals and laterals, but few changes have been noted farther away from these waterways.

On-farm wildlife habitat changes are monitored at representative sites throughout the valley, with long-term impacts of the irrigation practices evaluated. The on-farm program includes incentives for landowners to voluntarily apply replacement or enhancement practices. The 1984 legislation provides the authority to implement planned wildlife measures for Stage One, Stage Two, and on-farm losses. If habitat losses cannot be offset locally, the program provides for acquiring and developing as much as 4,000 acres of wildlife habitat.

SUMMARY

The Federal salinity control program assists local water users with line or pipe delivery systems to improve on-farm irrigation systems and irrigation water management. Such technology and practices reduce the seepage and associated salt loading. Since the beginning, 76 km (36 mi) of off-farm delivery systems have been lined or piped, about 232 km (145 mi) of on-farm delivery systems have been lined or piped, and improved irrigation systems have been installed on 3,880 ha (9,700 acres). The projected net decrease in annual salt loading as a result of these improvements is about 43,200 metric tons (48,000 tons), or a reduction of 4.3 mg/L in salinity concentration at Imperial Dam.

Semiautomated irrigation systems using recently developed technology have been successful. These systems reduce delivery seepage, help farmers manage water applications, and generally reduce the amount of water applied.

The Federal projects are 10–20 percent completed, with final program completion scheduled for the year 2000. When this is accomplished, the total projected decrease in annual salt loading is estimated to be about one-half of the total 522,000 metric tons. The salinity concentration at Imperial Dam should decrease by 25 mg/L. Aggressive monitoring and evaluation programs are assessing and quantifying the actual salinity reduction benefits of the combined cooperative effort between the Federal government and the water users.